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Improving buildings energy performance - Comparison between simple payback period and life cycle costs analysis

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ABSTRACT

The building sector is one of the Europe's main energy consumer, making buildings an important target for a wiser energy use, improving indoor comfort conditions and reducing the energy consumption. To achieve the European Union targets for energy consumption and carbon reductions it is crucial to act in new, but also in existing buildings, which constitute the majority of the building stock. In existing buildings, the significant improvement of their efficiency requires important investments. Therefore, costs are a major concern in the decision making process and the analysis of the cost effectiveness of the interventions is an important path in the guidance for the selection of the different renovation scenarios. The Portuguese thermal legislation considers the simple payback method for the calculations of the time for the return of the investment. However, this method does not take into consideration inflation, cash flows and cost of capital, as well as the future costs of energy and the building elements lifetime as it happens in a life cycle cost analysis. In order to understand the impact of the economic analysis method used in the choice of the renovation measures, a case study has been analysed using simple payback calculations and life cycle costs analysis. Overall results show that less far-reaching renovation measures are indicated when using the simple payback calculations which may be leading to solutions less cost-effective in a long run perspective.

INTRODUCTION

Buildings are an important target for the mitigation actions on the climate change. In Europe the building sector is responsible for 40% of the final total energy consumption and 36% of the CO_2 emissions (BPIE, 2011). In an attempt to make an effective action towards climate change mitigation, the European Parliament published the recast of the Energy Performance of Buildings Directive (EPBD) where the nearly zero energy building concept was introduced and established its mandatory implementation for new buildings after the end of 2020 (European Parliament, 2010). However, in order to achieve the carbon emission reduction targets for 2050, acting only on new buildings is not enough, mainly due to the low rate of replacement of the existing building stock (European commission, 2012).

Improving the energy performance of existing buildings, beyond reductions of energy consumption and carbon emissions, can reduce operational costs and can also have significant non-energy benefits, such as extended equipment life, increased lease rates, better indoor environmental quality and comfort conditions, improved market value and reduced exposure to energy price fluctuations (eere, 2011). The decision of improving a building performance is a risk management strategy and different market and policy risks can be reduced when the energy efficiency is improved (eere, 2011).

In order to analyse if a certain measure or renovation package of measures is cost-effective, usually cost/benefit analysis are performed, using several possible methods. The most simple method is the simple payback method calculation (eere, 2011). The payback period is the length of time required to recover the cost of an investment. The longer periods are the less desirable for investment positions (Investopedia, 2015). The simple payback does not take into account any benefits or costs that occur after the initial investment has been recovered.

The life cycle costs analysis is a more complex method, with the costs and benefits of each alternative being carefully analysed along their life time and expressed in net present value (NPV) (eere, 2011). It includes the investment costs, energy costs, operation and maintenance costs and any residual value of the building at the end of the period considered in the analysis (eere, 2011). Life cycle costs (LCC) is a more rigorous approach because it accounts with all cash outflows and inflows over the period under analysis and it also uses the value of the money to adjust the cash to its present value (eere, 2011).

METHOD

Based on a particular case study, the comparison between the assessment of different renovation scenarios using the simple payback calculations and life cycle costs analysis was carried out. For both cases, the same renovation packages were considered and analysed.
The energy needs were calculated in accordance with the Portuguese thermal regulation which follows the EN ISO 13790 considering a seasonal time-frame. The investment and maintenance costs were calculated using CYPE software® (cype, 2014). The energy prices were based on the Portuguese market energy costs, also considering the scenario given by the European Commission (European Commission, 2012b) for the estimation of the energy prices evolution for the calculation period.
For any analysis, the comparison is between a reference renovation scenario, where the energy performance of the building is not improved, and different energy related renovation scenarios. The reference case is a basic scenario that does not include any energy related renovation measure, but only measures to restore the building functionality and appearance.
The simple payback calculations allow calculating the time needed to recover the money invested in renovation measures improving the energy performance of the building, based on the energy savings achieved with those measures. It only takes into account investment costs and energy costs and it is expressed in equation 1.

$$Simple\ Payback\ period\ = \frac{Initial\ investement\ (€)}{Annual\ energy\ savings\ (€/year)} \quad (1)$$

The initial investment refers to the increase of costs in each renovation package of measures in comparison with the reference scenario. The energy savings represents the difference between the energy costs with the reference scenario and with each one of the alternative energy related renovation scenarios. The most attractive solutions will be the ones with shorter payback periods.
The life cycle costs analysis allows assessing the total costs of each alternative renovation scenario, during a selected life cycle. It includes the investment costs, operation and maintenance costs, replacement, disposal and, when analysed on the social perspective, it may also include the emissions costs. The renovation scenarios with lower global costs than the reference scenario are considered cost-effective and the one with the lowest global cost is the cost optimal scenario.

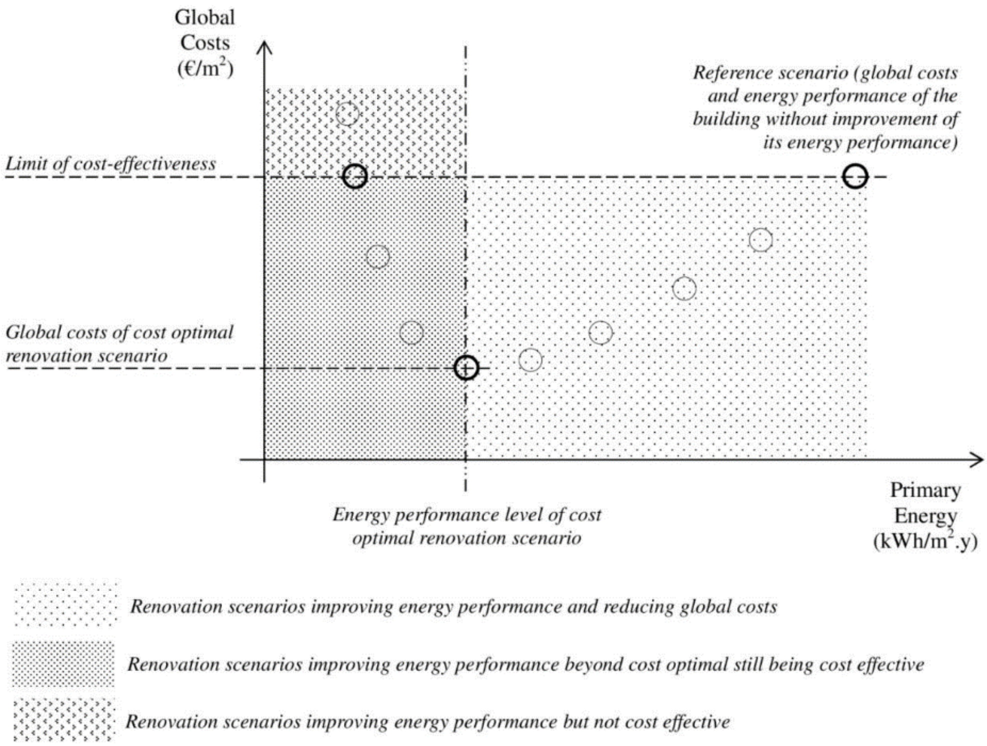

Figure 1 Graphic representation of the cost-effectiveness analysis using life cycle approach (Ferreira, et al, 2014a)

The life cycle costs analysis is more complex, taking into account the value of the money and tax rates. The discount rate considered in this study was 6%. The base process is similar to the payback period, comparing the reference case with different energy related renovation scenarios, but more costs are included and the best solution is the one which

presents lower global costs during the selected life cycle. For this study, the selected life cycle considered was 30 years (European Commission, 2012b) in accordance with the European guidelines.
Figure 1 shows the graphic representation of the life cycle costs method. All the packages with lower costs compared with the reference case are cost-effective and the package with the lowest global costs is the cost-optimal solution.

CASE STUDY AND RENOVATION SCENARIOS

The case study is a generic building from the Portuguese building stock. A generic building can be a real or a virtual building with the most common characteristics of the analysed building stock. The chosen building is a virtual single family building, from the period between 1960 and 1990. It presents the average areas and common constructive solutions for buildings from that period. The data to develop this building was collected from the database of the Portuguese energy certification system managed by the Portuguese Energy Agency (ADENE).
The building has stone walls with U-value of 1.76 W/m².ºC and light weight slabs on the floor and roof. The U-value for the roof is 2.80 W/m².ºC and for the floor is 1.65 W/m².ºC. The windows are single glazed windows with U-value of 4.10 W/m².ºC and a solar factor of 0.88, with external shutters. It has no insulation in any of the building's elements and the building's integrated technical systems (BITS) have low performances. For DHW (domestic hot water) there is a gas heater (η =0.67) and for heating there is an electric heater (η =1). The building is located in Braga, in the northwest part of Portugal.

Table 1 Summary of the analysed renovation measures for the building envelope

	Wall	Roof	Floor	Window
REF	Maintenance	Maintenance	Maintenance	Maintenance
SC1	Maintenance	RW* 80mm	Maintenance	Alum* U-value: 2,5 W/m².ºC
SC2	EPS* 40mm	RW 80mm	Maintenance	Alum U-value: 2,5 W/m².ºC
SC3	EPS 40mm	RW 80mm	RW 40mm	Alum U-value: 2,5 W/m².ºC
SC4	Maintenance	Maintenance	Maintenance	PVC* U-value: 2,4 W/m².ºC
SC5	Maintenance	Maintenance	RW 40mm	PVC U-value: 2,4 W/m².ºC
SC6	EPS 40mm	Maintenance	RW 40mm	PVC U-value: 2,4 W/m².ºC
SC7	EPS 40mm	RW 80mm	RW 40mm	PVC U-value: 2,4 W/m².ºC
SC8	EPS 50mm	RW 100mm	RW 60mm	PVC U-value: 2,4 W/m².ºC
SC9	EPS 60mm	RW 120mm	RW 60mm	PVC U-value: 2,4 W/m².ºC
SC10	EPS 80mm	RW 120mm	RW 80mm	PVC U-value: 2,4 W/m².ºC
SC11	EPS 100mm	RW 120mm	RW 80mm	PVC U-value: 2,4 W/m².ºC
SC12	EPS 100mm	RW 120mm	RW 80mm	PVC U-value: 2,1 W/m².ºC
SC13	EPS 160mm	RW 120mm	RW 80mm	PVC U-value: 2,1 W/m².ºC
SC14	EPS 180mm	RW 120mm	RW 80mm	PVC U-value: 2,2 W/m².ºC

*EPS – Expanded Polystyrene; RW – rock wool; Alum – aluminium frames; PVC –Polyvinyl chloride frames

Table 2 Summary of the analysed combinations of BITS

	Heating	Cooling	DHW (domestic hot water)	RES
REF	Elec. Heater η=1	HVAC EER 3,50	Gas heater η=0,8	_
BITS1	HVAC COP4,10	HVAC EER 3,50	Gas heater η=0,80	_
BITS2	Heat pump COP3,33	Heat pump EER2,68	Heat pump	_
BITS3	HVAC COP4,10	HVAC EER 3,50	Electric heater with storage tank η=0,80	Solar thermal
BITS4	Biomass boiler η=0,93	HVAC EER 3,50	Biomass boiler η=0,93	_
BITS5	Gas boiler η=0,92	HVAC EER 3,50	Gas boiler η=0,92	_
BITS6	Gas boiler η=0,92	_	Gas boiler η=0,92	_
BITS7	Biomass boiler η=0,93	_	Biomass boiler η=0,93	
BITS8	HVAC COP4,10	HVAC EER 3,50	Biomass boiler η=0,93	_

For the reference scenario, the building's energy performance is poor, with a primary energy use of 646 kWh/m².y, where 92% of this energy is for space heating. For this building, different renovation scenarios for the building's envelope were considered and analysed and are summarised in Table 1. Each one of these envelope solutions was combined with different building integrated technical systems (BITS), summarised in Table 2.
The analysed renovation measures and combination of BITS correspond to the most common energy related solutions in the Portuguese market. In the combinations there is always a renovation scenario where only the BITS are changed and another two where they are combined with solar thermal panels. There are some exceptions, namely BITS 4, 6 and 7 once previous calculations have shown that these combinations are not cost-effective (Ferreira, et al, 2014b).

RESULTS OF THE SIMPLE PAYBACK CALCULATIONS AND LCC ANALYSIS

Using the combination of the renovation measures previously described, the renovation scenarios were compared using the simple payback calculations and the LCC analysis. The simple payback calculations result in the number of years to recover the investment and the results of the life cycle costs analysis are presented in costs for the complete assessment of a certain renovation measure.

Simple payback calculations

The results for the simple payback period are presented in figure 2. In the figure, each bar represents the number of years that are necessary to recover the investment based on the calculated energy savings. Each group of bars is a renovation scenario for the buildings envelope, combined with each one of the 8 BITS. The bars from scenario SC7 to SC14 are the renovation measures that include insulation in all of the building elements. These scenarios have longer payback time than those including only the most cost-effective measures.
Specially in the first three BITS, the scenarios with longer payback time are the ones that include photovoltaic panels.
Based on the figure it is possible to conclude that the payback time is generally longer when the renovation packages improve the building envelope to higher levels of insulation, despite the BITS considered.

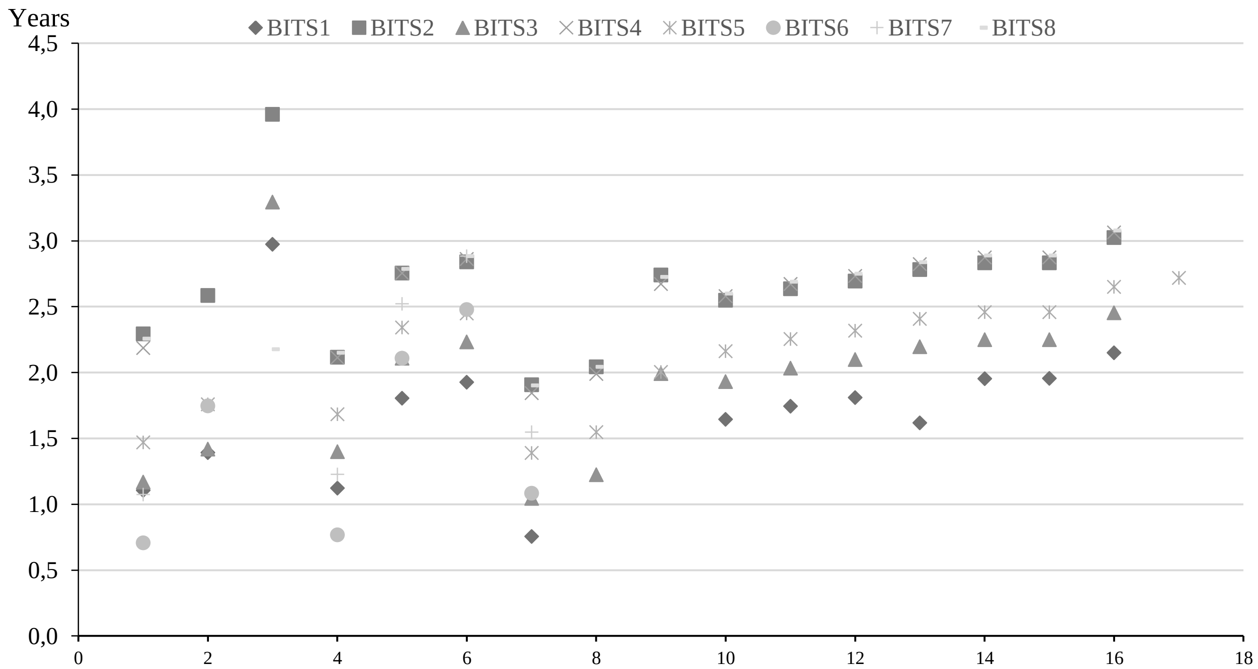

Figure 2 Simple payback analysis

In general, the solutions with lower investment involved are the ones with shorter payback time. The renovation scenarios that only include the replacement of the BITS are good examples. However, these solutions led to worse energy performances of the building.
Combinations including BITS 1, 3, 6 and 7 present lower payback period. The combination of very efficient BITS, such as the heat pump with photovoltaic panels, leads to higher investment costs and consequently to a longer payback time.
The scenario with shorter payback time is the renovation REF combined with the gas boiler for heating and DHW (BITS 6). This solution includes only maintenance, and does not consider a cooling system. It corresponds to a total

primary energy of 278 kWh/m².y. For the other BITS the best scenario is SC4, that includes maintenance and window replacement.

LCC analysis

Considering the LCC analysis, the results are different. Figure 3 shows the results for the life cycle analysis for all the renovation packages. With the LCC, all scenarios are cost-effective, which means they have lower global costs than the reference scenario for the 30 years life cycle.

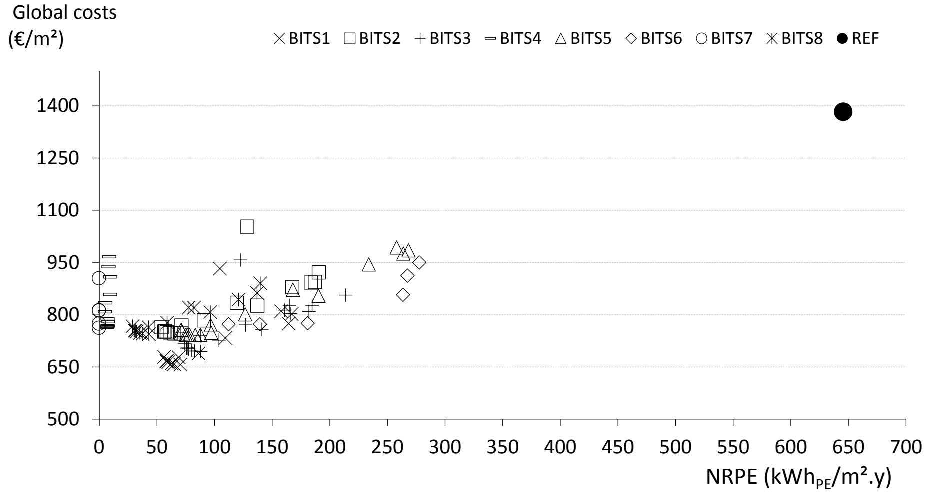

Figure 3 Results of LCC analysis for a 30 years life cycle

Looking at figure 3 it can be concluded that the best solution, so called cost optimal solution, is achieved with BITS 1 combined with renovation scenario 7 (SC7). This solution includes 4 cm of insulation on the walls and floor and 8 cm of insulation on the roof. It leads to a total primary energy consumption of 71 kWh/m².a. This value is less than half of the energy consumption of scenario SC4 (the best one, obtained with the simple payback calculations), using the same BTIS.

Close to this scenario there are others which reduce even more the energy consumption towards the zero energy and are still cost-effective during the building life cycle.

COMPARISON BETWEEN THE TWO METHODS

Despite having different focus and basis, comparing both methods allows seeing that BITS 1, 3 and 5 are the best in both methods and BITS 4, 7 and 8 are the worst, despite the different trend of the costs curves. This can be seen in figure 4. In the figure, the graphic from the left represents the simple payback calculations and the second one the LCC analysis.

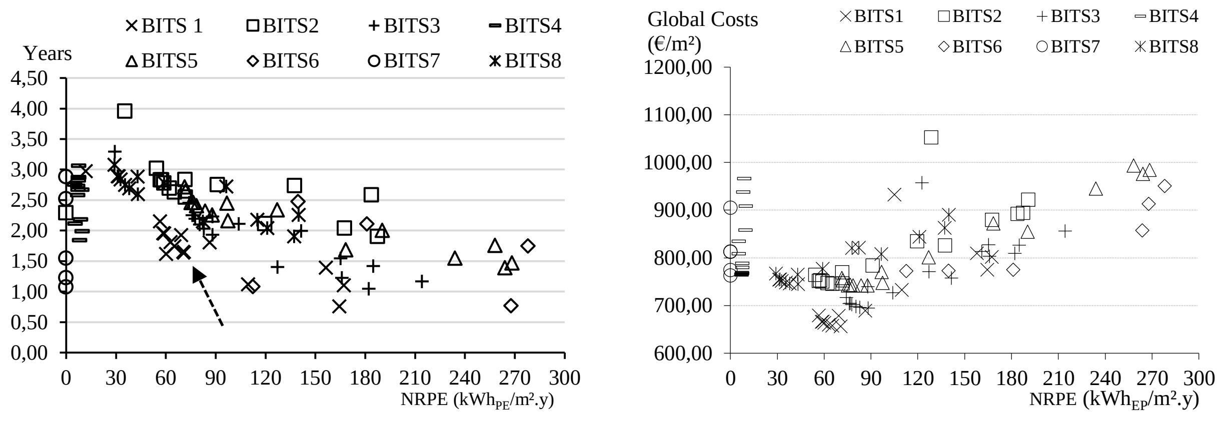

Figure 4 Comparison between the results of the simple payback calculations and LCC analysis

Looking at the figure, in the left side graphic, as the building envelope is improved, the costs rise, and the payback time increases. In the right side graphic with the LCC analysis, the scenarios with lower investment costs are the ones with higher global costs, due to higher operational costs during the buildings life cycle.
For the simple payback analysis, the best scenario is the SC4 despite the combination of BITS or REF scenario. For the LCC analysis, the best scenario is SC7 combined with different BITS. Scenario SC7 includes insulation in every element of the building envelope and BITS replacement. It may have a higher initial investment than the reference case and SC4, but during 30 years, this solution proves to be more cost-effective. With the simple payback method the SC7 has a payback of about a year and half, which places it among the scenarios with lower payback time, as it can be seen in figure 4 (cross marker indicated by the arrow).

CONCLUSIONS

In the decision making process for energy related renovation of existing buildings, cost-benefit analysis can be performed with simple methods such as simple payback calculations or more sophisticated ones like a life cycle costs analysis. Generally, all projects could be examined using either methods and both allow prioritising the renovation measures taking into account the best return on investment.
Comparing the simple payback and the LCC it can be seen that the methods involve different parameters for the calculations, but in general the BITS with shorter payback are also the most cost effective ones in LCC analysis.
Among the different intervention scenarios to improve the building envelope, the scenarios that were less attractive due to the high initial investment (higher simple payback time), become more attractive or even prove to be the best ones when a life cycle cost analysis is performed for the analysed period. Once the simple payback calculations only consider the initial investment and the energy savings, the cheapest solutions become the most attractive ones. This simplified analysis leads to the miss opportunity of improving the buildings energy performance in a more effective way.
The LCC analysis involves more costs incurred during the use of the building, creating a different balance among the renovation measures. The scenario with the best balance between energy savings and costs includes the improvement of all building envelope elements.
In the LCC analysis the most cost-effective scenarios lead to better energy performances than the ones obtained with the simple payback calculations.
In order to achieve the UE targets for the reduction of the energy consumption and carbon emissions, the LCC analysis seems more appropriate, because the most cost-effective solution presents a more effective reduction on the total energy consumption with consequent reduction of the carbon emissions, and a long term perspective is considered. Decisions on energy related building renovation based on simple payback calculation seems to be leading to missed opportunities to improve buildings to the most cost-effective level, increasing the future costs of the existing building stock.

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